Fisheries and Oceans Canada
Pêches et Océans Canada

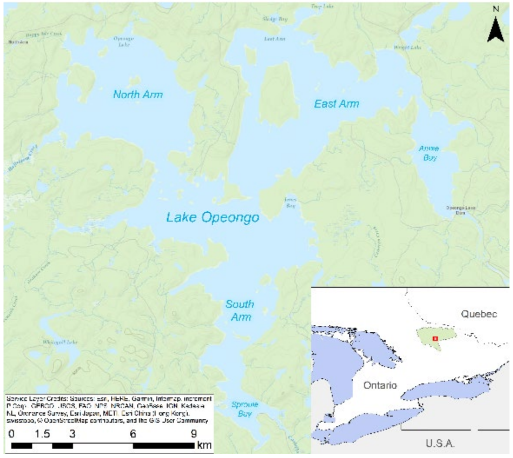
Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat
Science Advisory Report 2022/019

Ontario and Prairie Region

RECOVERY POTENTIAL ASSESSMENT OF LAKE WHITEFISH (*COREGONUS CLUPEAFORMIS*), LAKE OPEONGO LARGE-BODIED DESIGNATABLE UNIT AND LAKE OPEONGO SMALL-BODIED DESIGNATABLE UNIT

Lake Opeongo large-bodied (top) and small-bodied (bottom two) Lake Whitefish. Photo credit: Nick Mandrak, University of Toronto Scarborough.



Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 1. Map of Lake Opeongo, Algonquin Provincial Park, Ontario, where the Lake Opeongo large-bodied and small-bodied Designatable Units of Lake Whitefish are found.

Context:

*In April 2018, COSEWIC (Committee on the Status of Endangered Wildlife in Canada) assessed ten Designatable Units (DUs) of Lake Whitefish (*Coregonus clupeaformis*) representing five species pairs found in Yukon and Ontario lakes. The Lake Opeongo large-bodied and small-bodied DUs were assessed as Threatened as “the risk of establishment of invasive species that could alter the distinct ecological niches required to maintain the coevolved species pair” threatens their persistence. The Recovery Potential Assessment (RPA) process was developed by Fisheries and Oceans Canada (DFO) to provide information and scientific advice needed to fulfill requirements of the federal* Species at Risk Act *(SARA), including the development of recovery strategies and authorizations to carry out activities that would otherwise violate SARA (DFO 2007).*

*This Science Advisory Report is from the March 2–4, 2021 regional peer review on the Recovery Potential Assessment of Lake Whitefish (*Coregonus clupeaformis*), Lake Opeongo large-bodied Designatable Unit and Lake Opeongo small-bodied Designatable Unit. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

June 2022

SUMMARY

- The Lake Opeongo large-bodied and small-bodied designatable units (DUs) of Lake Whitefish (*Coregonus clupeaformis*) were assessed as Threatened by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) as a unique species pair found only in Lake Opeongo, Algonquin Provincial Park, Ontario (Figure 1). The large-bodied and small-bodied DUs have likely evolved to use different ecological niches in the lake. Lake Opeongo is the only known lake where a small-bodied DU of Lake Whitefish persists despite the presence of Cisco (*Coregonus artedi*; introduced in 1948).
- The greatest threat to both DUs is the introduction of new invasive species that could disrupt the ecological processes that maintain divergence in the species pair. Invasive zooplankton and fishes occur near Lake Opeongo and could be introduced by human-mediated mechanisms. Other threats include existing introduced species, climate change, and possibly human disturbances. The impact of these threats is not well known; however, in other lakes, introduced species are implicated in the loss of other Lake Whitefish species pairs.
- Habitat features required for the adult life stage of both DUs include areas of deep, cold water (not exceeding 20°C) in the hypolimnion and nearshore areas over hard substrates < 10 m in depth for spawning activities; eggs, in general, require hard substrates and cold overwinter temperatures with extensive ice cover for proper development; larvae require warming, productive surface waters initially for feeding and growth.
- Lake Opeongo has a total area of 5,860 ha. The minimum area required to support the large-bodied DU was determined to be ~4,900 ha and ~1,200 ha for the small-bodied DU, suggesting Lake Opeongo has sufficient habitat to support both DUs.
- Two population modelling scenarios were considered: one where the two DUs are reproductively isolated, and one where a single population is characterized by two alternative life-history strategies.
- When the two DUs are reproductively isolated, the impact of harm was sensitive to a DU’s population trajectory. The large-bodied DU is most sensitive to the juvenile stage when experiencing population growth, and is most sensitive to the adult stage when the population is stable or declining. The small-bodied DU is similarly sensitive across life stages under most population growth scenarios, but is less sensitive for the adult life stage when experiencing population growth.
- The minimum viable population (MVP) size was estimated as ~1,400 to ~2,300 adult females for the large-bodied DU, and ~4,100 to ~8,700 adult females for the small-bodied DU depending on catastrophe rate.
- Several knowledge gaps exist around the biological nature of the DUs. Key knowledge gaps also exist around the population size and trajectory, particularly for the small-bodied DU, and the impacts of existing and future invasive species.

BACKGROUND

The Lake Whitefish (*Coregonus clupeaformis*, Mitchill 1818) is a coldwater benthivore in the family Salmonidae with a broad distribution across North America. The species displays substantial phenotypic variation across its range, both within and between populations. Some populations contain two distinct forms in sympatry, a larger (usually benthic), “normal” form, and a smaller (usually limnetic), “dwarf” form, that have resulted from local adaptations. This degree of differentiation has made the species difficult to classify, and ultimately to assess and manage. Efforts to classify the species into Designatable Units (DUs) resulted in 36 DUs identified across Canada. Some DUs represent a single form with a broad geographic distribution whereas others represent members of species pairs found in isolation (Rogers 2009, Mee et al. 2015). The species pairs have diverged to differing degrees through different mechanisms and, as such, are unique to their lakes and represent discrete and significant units of whitefish diversity. Ten of these DUs representing species pairs from five Canadian lakes were identified for conservation prioritization and were assessed by COSEWIC in April 2018 (COSEWIC 2018). Two of these are found in Lake Opeongo, Ontario and are referred to as the Lake Opeongo large-bodied DU and small-bodied DU. It should be noted that COSEWIC used ”Opeongo Lake” during the assessment process; however, Lake Opeongo was preferred by meeting participants. Similarly, the two Lake Whitefish forms were referred to as “populations” by COSEWIC, but “Designatable Units” was preferred by meeting participants to avoid confusion regarding population structure. Both DUs were assessed by COSEWIC as Threatened, based on D2 Criteria of a restricted Index Area of Occupancy in a single location, and due to the risk of establishment of aquatic invasive species that could disrupt the ecological processes that drove divergence and maintains the species pair.

Fisheries and Oceans Canada (DFO) has developed a Recovery Potential Assessment (RPA) process to provide information and scientific advice related to current population status and trends, threats to survival and recovery, and feasibility of recovery. This advice is needed to fulfill various requirements of the *Species at Risk Act* (SARA), including informing listing decisions, development of recovery documents, and assessing SARA Section 73 permit applications. A RPA for the Lake Opeongo Lake Whitefish (large-bodied and small-bodied DUs) was undertaken March 2–4, 2021. Supporting information is found in Colm and Drake (2021) and Fung et al. (2021).

ASSESSMENT

Biology

The Lake Whitefish is generally silvery with little colouration on the fins (Scott and Crossman 1998). It has an elongate body shape that is somewhat laterally compressed. The dorsal fin has 11–13 soft rays; there is an adipose fin; the caudal fin is deeply forked; the anal fin has 10–14 rays; and, a pelvic axillary process is present. It has a relatively short head, a small eye, two nostril flaps and a snout that overhangs a small, subterminal mouth. It has large, cycloid scales that are variable in number along the lateral line. The species has a thick mucous layer. Older individuals may develop a hump behind the head and prominent nuptial tubercles develop on breeding males and, to a lesser extent, on breeding females (Scott and Crossman 1998). In Lake Opeongo, Lake Whitefish occurs with other coregonines: Round Whitefish (*Prosopium cylindraceum*) and Cisco (*Coregonus artedi*).

Two distinct Lake Whitefish forms in Lake Opeongo were first documented by Kennedy (1943), distinguished by a bi-modal size distribution of mature adults (Table 1), and both DUs have recently (2010s) been confirmed in the lake by Ontario Ministry of Natural Resources and Forestry (OMNRF) gill net surveys. These two data sets present similar age and growth patterns, and comprise most[1] of the information known about these DUs. Historically, the large-bodied form had a mean adult standard length (SL) of 251 mm, matured later (ages 4–7; scale ages), grew faster, lived longer (up to age 14) and had a mean (± SD) of 27.7 (± 1.1) gill rakers and 83.3 lateral line scales (Kennedy 1943). Most recently, mature large-bodied individuals had a mean fork length (FL) of 301 mm and were aged 4–24 (otolith ages; OMNRF unpublished data). Historically, the small-bodied form had a mean adult SL of 126 mm, did not exceed 160 mm SL, matured earlier (age 2; scale ages), grew slower, was shorter-lived (up to age 5) and had a mean (± SD) of 25.4 (± 0.14) gill rakers and 77.3 lateral line scales (Kennedy 1943). Most recently, mature small-bodied individuals had a mean FL of 145 mm, did not exceed 180 mm FL, and were aged 2–8 (otolith ages; OMNRF unpublished data). Due to difficulties in differentiating immature individuals, early life history data cannot be separated by DU.

Table 1. Summary of sizes of large-bodied and small-bodied forms of Lake Whitefish in Lake Opeongo from historic (Kennedy 1943) and current (OMNRF unpublished data from 2010s) data sets. Size cut-offs represent bins used to differentiate mature adults from each data set. Equations used to convert standard length (SL) and fork length (FL) to total length (TL) were based on Lake Whitefish from other populations (Fishbase 2020).

DU	Size Cut-off		Mean		Mode	
	Historic	Current	Historic	Current	Historic	Current
Large-bodied	> 160 mm SL (189 mm TL)	> 190 mm FL (213 mm TL)	251 mm SL (295 mm TL)	301 mm FL (332 mm TL)	240 mm SL (282 mm TL)	249 mm FL (275 mm TL)
Small-bodied	< 150 mm SL (176 mm TL)	< 180 mm FL (196 mm TL)	126 mm SL (148 mm TL)	145 mm FL (160 mm TL)	120 mm SL (141 mm TL)	149 mm FL (165 mm TL)

Lake Opeongo is one of 18 lakes in Canada known to contain a sympatric species pair of whitefish. In Lake Opeongo, the large-bodied DU has fewer gill rakers and may occupy shallower waters than the small-bodied DU, suggesting it may occupy a limnetic niche and the small-bodied a benthic niche. This is in contrast to observations of species pairs elsewhere; however, other life history traits (e.g., growth, age and size at maturity) do align with other pairs (Mee et al. 2015). Further examination of diet, gill raker counts, and habitat use is needed to confirm niche use of the Lake Opeongo pair.

Current Species Status

The Lake Opeongo large- and small-bodied DUs of Lake Whitefish are found only in Lake Opeongo, Algonquin Provincial Park, Ontario. The lake area is 58.6 km^2 and consists of three arms (East, North and South) connected by channels. Movement out of the lake may be possible over the Annie Bay fixed-crest weir dam during high water events.

The large- and small-bodied forms of Lake Whitefish were first detected in Lake Opeongo by Kennedy (1943) using multi-panel gill net gangs. Kennedy (1943) captured at least 524 large-bodied individuals and at least 167 small-bodied individuals in 1939 and 1940. The large-bodied DU has been consistently detected in the lake since this time during a variety of targeted and non-targeted sampling events (see Colm and Drake 2021 for a summary). Recent biological

---

[1] Additional data from OMNRF surveys from the 1980s exist and were brought up during the peer-review meeting. These data suggest different patterns of age and growth for the small-bodied form compared to historic or contemporary samples. These data were not included in the Research Documents due to a lack of information regarding collection and analysis methods. Other information regarding Lake Whitefish in Lake Opeongo exist; however, the two forms were not distinguished.

information on the large-bodied DU (n = 135) comes from surveys in 2010, 2018 and 2019 (OMNRF unpublished data). Targeted sampling for the small-bodied DU using small-mesh gill nets confirmed its persistence (n = 23 individuals) in the lake in 2018 (OMNRF unpublished data).

Two estimates of abundance were made for the large-bodied DU in Lake Opeongo (OMNRF unpublished data): 11,378 (95% Confidence Interval (CI) 6,509, 18,712) made from counts from 64 m gill net sets from 2010, and 22,792 (95% CI 10,437, 54,414) made from detection-corrected counts from 50 m gill nets from 2019. The difference in these two estimates is likely related to methodologies. There are currently no estimates available for the small-bodied DU and it is poorly sampled likely due to size selectivity issues with gears used.

Population Assessment

To assess the DU status (traditionally, Population Status), both DUs were ranked in terms of abundance (Relative Abundance Index; Extirpated, Low, Medium, High, or Unknown) and trajectory (Trajectory; Increasing, Decreasing, Stable, or Unknown). A certainty value was assigned based on the type of information used to assess the DU (1 = quantitative analysis, 2 = catch per unit effort, 3 = expert opinion). The Relative Abundance Index and Trajectory were combined to yield a DU Status (Table 2). Refer to Colm and Drake (2021) for detailed methods used to assess the DU Status.

Table 2. Designatable Unit (DU; i.e., Population) Status of Lake Whitefish in Lake Opeongo, resulting from an analysis of both the Relative Abundance Index and Trajectory. Certainty assigned to each DU Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index, or Trajectory).

DU	DU Status	Certainty
Large-bodied	Fair	2
Small-bodied	Unknown	3

Habitat Requirements

Summer habitat use by adult large- and small-bodied Lake Whitefish in Lake Opeongo is generally cold (7.6–20.0°C, with the greatest occupancy observed at 7.7–13.6°C [Challice et al. 2019]), deep water in the hypolimnion. Kennedy (1943) found some differences in occupied depths (and temperatures) between the two forms throughout the summer. In June, large-bodied individuals were captured in approximately 3 m of water (where water temperatures ranged from 7–16°C), and small-bodied individuals were captured in depths between 6 and 12.2 m (7–14°C). In August, the large-bodied form concentrated at shallower depths of 9 m (15°C), and the small-bodied form concentrated at 15.2 m (9°C), but this difference was largely driven by two nets, one with a large concentration of large-bodied individuals, and another with a large concentration of small-bodied individuals. The two forms were otherwise found at similar depths and temperatures (Kennedy 1943). Dissolved oxygen (DO) has not been found to be limiting in Lake Opeongo. Adult Lake Whitefish move into spawning grounds in late October through November, when water temperatures reach 4–7°C (Ihssen et al. 1981). Lake Whitefish generally spawns in depths less than 7.6 m over hard substrates (Scott and Crossman 1998). Ihssen et al. (1981) noted that the lake contains many granite rock ledges and cobble shoals close to shore where spawning likely occurs. Eggs remain on the spawning grounds to develop over winter. Winter habitat use by adults in Lake Opeongo is not known.

Little is known about the habitat occupied by juvenile Lake Whitefish in Lake Opeongo. Kennedy (1943) and OMNRF (unpublished data) caught immature individuals with mature large- and small-bodied individuals, suggesting that juveniles can occupy habitats similar to adults. Larval Lake Whitefish (not differentiated by DU) were captured nearshore overtop of spawning grounds at numerous locations around the lake when surface water temperatures were 6.5–9.5°C (Ihssen et al. 1981, Cucin and Faber 1985). The larval fish remain in surface waters for approximately six weeks, then likely retreat to intermediate depths (i.e., not as deep as final adult habitat) for the remainder of the summer.

Functions, Features, and Attributes

A description of the functions, features, and attributes associated with the habitat of large- and small-bodied Lake Whitefish in Lake Opeongo can be found in Table 3. The habitat required for each life stage has been assigned a life history function that corresponds to a biological requirement of Lake Whitefish. In addition to the life history function, a habitat feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the persistence of the species. Habitat attributes have also been provided, these are measurable components describing how the habitat features support the life history function for each life stage. This information is provided to guide any future identification of critical habitat for this species. Information is provided for Lake Opeongo DUs where available, and supplemented with general information on Lake Whitefish from elsewhere when necessary.

Table 3. Summary of the essential functions, features, and attributes for each life stage of Lake Whitefish in Lake Opeongo. Habitat attributes from published literature and those recorded during recent Lake Whitefish captures in Lake Opeongo have been used to determine the habitat attributes required for the delineation of critical habitat. Information is assumed to be the same for the large- and small-bodied DUs where they are not differentiated.

Life Stage	**Function**	**Feature (s)**	**Habitat Attribute (s)**	
			Scientific Literature	**Critical Habitat**
Spawn to hatch	Spawning (late October through November)	nearshore areas over hard substrates	• water temperatures 4–7°C (Ihssen et al. 1981) • granite ledges and rocky shoals (Ihssen et al. 1981, Cucin and Faber 1985) • depth range approximately 3–5 m (Cucin and Faber 1985); generally, water depths < 8 m (Scott and Crossman 1998) • ~10–50 m from shore (Cucin and Faber 1985)	nearshore (up to 50 m offshore) areas over hard substrates (granite ledges and rocky shoals), less than 8 m in depth, especially in East and South arms
	Egg Development (over winter)	hard substrates; cold temperatures; extensive ice cover	• granite or limestone ledges or shoals (with rock, cobble, gravel) free of fine sediments (Hart 1930, Fudge and Bodaly 1984, Freeberg et al. 1990, Jude et al. 1998, McKenna and Johnson 2009) • generally, water temperatures 0.5–8.1°C (Price 1940, Brooke 1975) • generally, cold winters with extensive cover to protect eggs from disturbance/displacement (Freeberg et al. 1990, Jude et al. 1998, McKenna and Johnson 2009)	-
	Hatch (days after ice out, late April through May)	warming, productive waters (epilimnion)	• water temperatures 4–8°C (Ihssen et al. 1981, Cucin and Faber 1985)	-
Larval (up to ~ 6 weeks after hatch)	Nursery; feeding	warming, productive waters (epilimnion)	• warming surface waters with temperatures 4–8°C upon hatch, achieving 6.5–12°C (Ihssen et al. 1981, Cucin and Faber 1985), generally, within upper 0.3–1 m (Hart 1930, Reckahn 1970, Freeberg et al. 1990, Herbst et al. 2011) over depths of 1.5–10 m directly over or near spawning areas (Cucin and Faber 1985) • generally, abundant zooplankton prey (Hart 1930, Freeberg et al. 1990, Cucin and Faber 1985)	warm, productive surface waters over depths up to 10 m (generally same as above)

Life Stage	**Function**	**Feature (s)**	**Habitat Attribute (s)**	
			Scientific Literature	**Critical Habitat**
Age 0 (~50 mm, or when first ontogenetic diet shift occurs)	Feeding	Cool waters of intermediate depths	• unknown in Lake Opeongo • In Great Lakes populations, age 0 individuals move below surface and occupy benthic habitats that are shallower than final adult habitat (Hart 1930, Claramunt et al. 2010, Pothoven et al. 2014)	-
Juvenile (age 1 to onset of maturity [~age 4-5 for large-bodied DU; age 2 for small-bodied DU])	Feeding	cold, deep water in the hypolimnion	• generally, same habitat as adults • laboratory experiments suggest preferred thermal range (age 1) of 15.5–19.5°C; 18.5°C optimum for growth (Edsall 1999a,b)	areas of deep, cold water, not exceeding 20°C
Adult	Feeding	cold, deep water (hypolimnion) with access to pelagic and benthic invertebrates	• water depths ranging from 3–18 m • summer water temperatures 7–14°C, not exceeding 20°C (Kennedy 1943, Challice et al. 2019) • abundant Cladocera, Ephemeroptera larvae (notably in May), Chironomidae, and bivalve *Pisidium* sp. (Sandercock 1964)	areas of deep, cold water, not exceeding 20°C
Adult (large-bodied DU)	Feeding	cold, deep water (hypolimnion)	• may occupy shallower, warmer water occasionally during summer months (3 m depth with temperatures 7–16° C in June, and 9 m depth and 15° C in August [Kennedy 1943])	-
Adult (small-bodied DU)	Feeding	cold, deep water (hypolimnion)	• may occupy deeper, cooler water occasionally during summer months (6–12 m depth with temperatures 7–14° C in June, and 15 m depth and 9° C in August [Kennedy 1943])	-

Threat Assessment

Human Intrusions and Disturbances

Lake Opeongo is the most visited lake within Algonquin Provincial Park for both recreational angling and backcountry camping and is one of two lakes in the park that permits unlimited horsepower vessels. Creel survey data from Lake Opeongo suggests that Lake Whitefish is infrequently targeted (annual average of 42 angler hours spent), captured (annual average catch of 13), or harvested (annual average of 7 taken; OMNRF unpublished data). Direct and indirect (e.g., bycatch) impacts from recreational fishing are likely minimal to Lake Whitefish, but may be more important for the large-bodied DU as it is more likely to be captured, and is more susceptible to perturbations to the adult life-stage (Fung et al. 2021). Additional impacts from recreational vessels (e.g., mortalities, physiological and behavioural impacts, habitat disturbances including increased turbidity and changes to invertebrate communities) may be more important for the large-bodied DU if it regularly occupies shallower waters, but would likely only affect a small proportion of the population in the vicinity of the disturbance.

Invasive and Other Problematic Species and Genes

Aquatic invasive species are thought to be the greatest threats facing most sympatric whitefish pairs as they are likely to disrupt the ecological conditions that drive and maintain divergence of the two forms (Mee et al. 2015, Reid et al. 2017, COSEWIC 2018). Two fish species have been introduced into Lake Opeongo, Smallmouth Bass (*Micropterus dolomieu*; early 1900s) and Cisco (in 1948). Kennedy (1943) documented the Lake Whitefish species pair after the establishment of Smallmouth Bass, so impacts from this species are unknown. Sympatric pairs of Lake Whitefish are usually only known from lakes where Cisco is absent as it is thought Cisco have a competitive advantage over the small-bodied form in the limnetic niche (Pigeon et al. 1997, Trudel et al. 2001, Mee et al. 2015); however, both DUs have persisted following the introduction of Cisco. Other aquatic invasive species have impacted sympatric Lake Whitefish pairs elsewhere. It is hypothesized that the introduction of Spiny Waterflea (*Bythotrephes longimanus*) may be responsible for the replacement of the Lake Whitefish pair with a single, larger form in Como Lake, Ontario (Reid et al. 2017). The introduction of Rainbow Smelt (*Osmerus mordax*) has also led to a decline in Lake Whitefish populations in many lakes in eastern North America containing either a species pair or a single form, due to competitive interactions at the larval stage and/or predation on newly hatched Lake Whitefish by adult Rainbow Smelt (Loftus and Hulsman 1986, Evans and Waring 1987, Gorsky and Zydlewski 2013, Wood 2016). The latter two invasive species are of greatest concern given their impacts on Lake Whitefish pairs elsewhere, their proximity to Algonquin Provincial Park, and, in the case of Spiny Waterflea, the likelihood of accidental human-mediated introduction. Further information is needed on the trophic niches of each DU to better understand how future invasive species could disrupt the species pair.

Climate Change and Severe Weather

Warming temperatures and reduced ice cover are two outcomes of climate change most likely to negatively impact Lake Whitefish in Lake Opeongo, based on forecasted and observed changes already occurring in Algonquin Park and limiting factors to the species known from elsewhere (Ridgway and Middel 2020). Warming water temperatures are likely to impact thermally sensitive egg development over the winter, may lead to a mismatch in larval hatch and zooplankton abundance in the spring, and reduced ice cover may lead to decreased egg over-winter survival as ice is thought to protect eggs from disturbance and displacement (Freeberg et al. 1990, Jude et al. 1998, Pothoven 2020). Warming temperatures may also impact habitat use of this coldwater species. Lake Whitefish may be unable to forage in surface waters in the spring without thermal consequences, prolonged lake stratification may restrict coldwater habitat space and increase hypoxic conditions where Lake Whitefish reside, and both the large- and small-bodied DUs of Lake Whitefish in Lake Opeongo could be forced to shift to the same habitat and food sources to avoid thermal stress, which could lead to niche overlap and, ultimately, loss of the pair (Gorsky et al. 2012, Guzzo and Blanchfield 2017, Ridgway and Middel 2020). Additional indirect impacts related to changes in food web structure and algal blooms resulting from climate change may also negatively impact the Lake Opeongo Lake Whitefish pair. Threats from climate change were considered over a 10 year timeframe (~1–2 generations).

Cumulative Threats

Threats are often considered independently during threat assessments, but may interact in complex and context-dependent ways. They may be additive (effect is equal to the sum of the impacts of each threat on its own), synergistic (effect is greater than the sum of the impacts of each threat on its own), or antagonistic (effect is dampened relative to each threat on its own). The potential for cumulative impacts is an important consideration, but more work is needed to determine the interactive and cumulative impacts of the threats acting on Lake Opeongo Lake Whitefish large- and small-bodied DUs.

Threat Level Assessment

The threat assessment was completed for Lake Opeongo Lake Whitefish large- and small-bodied DUs following guidelines provided in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence, threat Level of Impact, and Causal Certainty. The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in a Threat Risk Matrix resulting in the DU-Level Threat Risk with associated Causal Certainty. Terms used to describe threat categories are described in Table 4 and results are summarized in Table 5. Refer to Colm and Drake (2021) for detailed methods.

Table 4. Terms and definitions used to describe causal certainty, and population (in this case, Designatable Unit) level threat occurrence (PTO), threat frequency (PTF) and threat extent (PTE) reproduced from DFO (2014).

Term	Definition
Causal Certainty (CC)	
Very high (1)	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified
High (2)	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery
Medium (3)	There is some evidence linking the threat to population decline or jeopardy to survival or recovery
Low (4)	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery
Very low (5)	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery
Population-Level Threat Occurrence (PTO)	
Historical (H)	A threat that is known to have occurred in the past and negatively impacted the population.
Current (C)	A threat that is ongoing, and is currently negatively impacting the population.
Anticipatory (A)	A threat that is anticipated to occur in the future, and will negatively impact the population.

Term	Definition
Population-Level Threat Frequency (PTF)	
Single (S)	The threat occurs once.
Recurrent (R)	The threat occurs periodically, or repeatedly.
Continuous (C)	The threat occurs without interruption.
Population- Level Threat Extent (PTE)	
Extensive (E)	71-100% of the population is affected by the threat.
Broad (B)	31-70% of the population is affected by the threat.
Narrow (NA)	11-30% of the population is affected by the threat.
Restricted (R)	1-10% of the population is affected by the threat.

Table 5. Designatable unit-level Threat Assessment for Lake Whitefish in Lake Opeongo. Threat Risk is a combination of the DU-level Likelihood of Occurrence and Level of Impact, with associated Causal Certainty value.

Threat	**Large-bodied DU**				**Small-bodied DU**			
	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent	Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Human Intrusions and Disturbances	Low (5)	H, C, A	R	R	Low (5)	H, C, A	R	R
Invasive and other Problematic Species and Genes	High (2)	H, C, A	C	E	High (2)	H, C, A	C	E
Climate Change and Severe Weather	Low (3)	C, A	C	B	Low (3)	C, A	C	B

Mitigations and Alternatives

Threats to Lake Whitefish survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects resulting from works, undertakings, or activities in Lake Opeongo. DFO has developed guidance on mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Central and Arctic Region (now Ontario and Prairie, and Arctic regions; Coker et al. 2010). This guidance should be referred to when considering mitigations and alternative strategies for habitat-related threats. Mitigations and alternatives for invasive and other problematic species and genes (i.e., non habitat-related threats) are found below.

Mitigation

- Promote public awareness campaigns for anglers and visitors to the park (i.e., surrounding bait legislation and proper cleaning, draining, and drying of vessels and equipment), and encourage the use of existing invasive species reporting systems (e.g., EDDMapS, Invading Species Awareness Program Hotline, iNaturalist).
- Conduct early detection surveillance or monitoring for invasive species that may negatively impact Lake Whitefish or alter food web dynamics in the lake.

- Implement a rapid response plan if invasive species are detected aimed at eradication or control (Locke et al. 2010).
- Boat washing stations, other vessel restrictions/conditions of use.
  - Lake Opeongo is one of two lakes in Algonquin Provincial Park to allow unlimited horsepower vessels (36 other lakes allow limited power vessels; Ontario 2013); it is more likely to receive AIS through accidental spread from contaminated vessels.

Alternatives

- Unauthorized introductions
  - There are no alternatives for unauthorized introductions because these should not occur.
- Authorized introductions
  - Use only native species.
  - Do not introduce Lake Whitefish from other populations.
  - Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 2017).

Recovery Modelling

Reproductive isolation between the large- and small-bodied DUs is inferred based on morphological evidence from Kennedy (1943) and genetic evidence from other Canadian sympatric whitefish pairs (Mee et al. 2015). Recovery potential modelling was conducted assuming the two DUs are reproductively isolated populations. As a precaution, an alternative population structure scenario was also considered, where the two DUs are a single population displaying two alternative life-history strategies. This helps inform whether the uncertainty around population structure is important for the advice on managing Lake Whitefish in Lake Opeongo.

Information on vital rates was compiled to build projection matrices that incorporate environmental stochasticity, and density-dependence acting on the first year of life. The impact of anthropogenic harm to populations was quantified with the use of elasticity and simulation analyses. Estimates of recovery targets for abundance and habitat were made with estimation of the minimum viable population (MVP) and the minimum area for population viability (MAPV). Refer to Fung et al. (2021) for complete methods.

Allowable Harm

In general, sensitivity to changes in vital rates is dependent on the current population growth rate for both DUs. For the large-bodied DU, adult survival has the strongest effect for populations at stable or declining growth rates, while growth rate becomes more sensitive to juvenile survival when the population is growing or booming. For the small-bodied DU, adult survival has the strongest effect at declining or stable population growth rates and decreases as growth rate increases. Fertility, young of the year (YOY) and juvenile survival have similar elasticity values which increase (i.e., their impact increases) as growth rate increases. The simulation analysis evaluating impacts of transient/periodic harm (as opposed to permanent harm assumed with the elasticity analysis) showed a similar trend, that the impact of harm is greater when applied to juvenile and adult stages than the YOY stage.

In the alternative scenario where Lake Opeongo Lake Whitefish form a single population with two alternative life history strategies, the population growth rate is most sensitive to large-bodied adult and juvenile survival rates at stable or declining populations, while at growing or booming growth rates, small-bodied vital rates (fertility, juvenile and adult survivals) exert a stronger impact. The proportion of large-bodied individuals in the population exhibits the most variable effect on growth rate where, for growth rates below a certain threshold, an increase in the proportion of large-bodied individuals would provide an increase to the overall population growth rate but above that threshold, growth rate is increased by increasing the proportion of small-bodied individuals. The simulation analysis showed that the impact of periodic harm is greater to the large-bodied DU than the small-bodied DU when applied to juvenile and adult stages. Harm applied to either DU on its own cannot drive the entire population to extinction, but can eliminate that DU from the population. If both DUs are equally represented in the population, applying harm to a single DU can potentially reduce the total population to 50% of the carrying capacity or lower (through elimination of that DU), and this is more likely to happen through application of harm to the large-bodied DU.

Recovery Targets

Abundance (MVP)

The frequency of catastrophes has a strong impact on the population size required for sustainability. In general, it requires 1.5 to 2 times the number of female adults to sustain the population under a 15% generational catastrophe rate compared to the 10% rate. Without further information on which rate is most appropriate, considering the 15% catastrophe rate is the more conservative approach.

The number of adult female large-bodied individuals required for a 99% probability of persistence over 100 years is ~1,400 and ~2,300 for 10% and 15% catastrophe rates, respectively. The number of female small-bodied individuals required is ~4,100 and ~8,700 for the 10% and 15% catastrophe rates, respectively. Under the alternative life-history scenario, the total number of adult females required is ~1,200–2,300 for the 10% catastrophe rate and ~ 1,900–4,200 for the 15% rate, depending on the proportion of large-bodied individuals in the population.

Assuming a stable age structure and based on the maturity schedule, the number of adult females can be converted to a population consisting of both sexes and juveniles. The large-bodied DU MVP is ~11,000 for the 10% catastrophe rate and ~19,200 for the 15% catastrophe rate. The small-bodied DU MVP is ~11,000 and ~24, 000 for the 10% and 15% catastrophe rates, respectively. Under the alternative life-history scenario, the MVP is ~8,600 and ~14,700 for the 10% and 15% catastrophe rates, respectively, using the highest female adult estimate from the range of proportions of large-bodied individuals. The large-bodied DU was recently estimated to have a population size of 22,792 (OMNRF unpublished data) suggesting it is likely above MVP. Similarly, if Lake Opeongo Lake Whitefish forms a single population with two alternative life history strategies, the recent population estimate suggests it is above MVP.

Habitat (MAPV)

Estimates of MAPV were converted to habitat requirements by dividing MVP by mean estimates of density to estimate the minimum area for population viability. The large-bodied DU has an estimated density of 3.9 individuals per ha (based on the recent population size estimate of 22,792 [OMNRF unpublished data]), thus, the MVP of 19,200 individuals requires an area of approximately 49 km^2. Density for the small-bodied DU was estimated to be 20.1/ha, which produces a habitat requirement of 12 km^2 for the MVP of 24,000 individuals. Lake Opeongo has an area of 58.6 km^2, and, therefore, provides a sufficient amount of habitat for both DUs.

Time to recovery

Simulations were used to estimate time to recovery assuming low abundance, as there are no estimates of abundance for the small-bodied DU. Simulations reflect a situation where there is an increase in available habitat or removal of threats or competitors (e.g., Cisco) such that vital rates return to a state that permits population size to increase towards carrying capacity. Ninety-five percent of populations reached recovery in 24 years or less.

Sources of Uncertainty

Many sources of uncertainty exist surrounding the biological nature of the Lake Opeongo Lake Whitefish large- and small-bodied DUs. Several of these knowledge gaps could have significant consequences for the recovery potential modelling. Current life history parameters (e.g., fecundity, maturity, growth rates) of both populations are lacking. The available information is old, some pre-dates the introduction of Cisco in 1948, and/or is only available for the large-bodied DU. Additional data from OMNRF surveys in the 1980s (currently unavailable) suggest a different mean size and ultimate age for the small-bodied DU than was found by Kennedy (1943) or in more recent sampling in the 2010s; however, details regarding the collection and interpretation of these data need to be resolved and the data made available. If the noted differences in size and longevity of the small-bodied DU are found to be more reflective of the current population parameters, the population trajectories and MVP estimates should be expected to be more similar to those of the large-bodied DU. Direct genetic evidence of reproductive isolation between the large- and small-bodied Lake Whitefish DUs does not exist, but reproductive isolation is inferred based on morphological differences and genetic evidence from other sympatric whitefish pairs in Canada. It is unknown which model scenario best represents the true population structure (i.e., whether populations are reproductively isolated or are displaying two alternative life history strategies). Two population structure scenarios were modelled in the interest of thoroughness and as a precaution; should genetic evidence become available, advice is presented for either outcome. Lastly, the frequency of catastrophic events for Lake Whitefish in Lake Opeongo remains an uncertainty. This had significant impacts on estimates of MVP, regardless of the modelled population structure.

Additional knowledge gaps were also identified around the abundance and population trends, habitat use, and distribution through the lake. Population abundance data and trends through time are lacking, especially for the small-bodied DU. Standardized, long-term monitoring using gears with appropriate size selectivity is needed to fill this gap. Age, size and maturity data must also be collected to differentiate the two DUs. The trophic and habitat (behavioural) niches of both DUs are not well understood. Limited depth observations from Lake Opeongo suggest the small-bodied DU may occupy deeper depths than the large-bodied DU, at least during some times of the year; this is in contrast to habitat use of species pairs elsewhere. This could be resolved with habitat models evaluating depth, water temperature and dissolved oxygen associations. Diet data would also help to differentiate niche utilization. Habitat use of age-0 individuals and juvenile (immature) small-bodied individuals is not known. Limited information from Great Lakes populations was presented to supplement habitat descriptions for age-0 fish, but may not be reflective of habitat use in Lake Opeongo. It is not known if both DUs are found in all three arms of the lake. The small-bodied DU has not been detected in the North Arm; however, suitable sampling may not have occurred there. It is also unclear if partial stream habitats in Lake Opeongo are used by either Lake Whitefish DU, or if individuals may move out of the lake (i.e., over Annie Bay dam) during high water events.

Finally, uncertainties around the impact of past threats remain. Two fish species were introduced into Lake Opeongo, the Smallmouth Bass in the early 1900’s and Cisco in 1948. The effects of these past species introductions on the Lake Opeongo large- and small-bodied Lake Whitefish DUs are unknown.

LIST OF MEETING PARTICIPANTS

Name	Organization/Affiliation
Julia Colm	DFO – Science, Ontario and Prairie Region
Andrew Drake	DFO – Science, Ontario and Prairie Region
Simon Fung	DFO – Science, Ontario and Prairie Region
Margaret Goguen (Rapporteur)	DFO – Science, Ontario and Prairie Region
Marten Koops	DFO – Science, Ontario and Prairie Region
Todd Morris (Chair)	DFO – Science, Ontario and Prairie Region
Tom Pratt	DFO – Science, Ontario and Prairie Region
Adam Rego (Rapporteur)	DFO – Science, Ontario and Prairie Region
Adam van der Lee	DFO – Science, Ontario and Prairie Region
Paul Grant	DFO – Science, Pacific Region
Jenni McDermid	DFO – Science, Gulf Region
Luiz Mello	DFO – Science, Newfoundland and Labrador Region
Bill Glass	DFO – FFHPP, Ontario and Prairie Region
Darcy McGregor	DFO – Policy and Economics, Ontario and Prairie Region
Joshua Stacey	DFO – Species at Risk, Ontario and Prairie Region
Alan Bell	OMNRF – Science and Research
Trevor Middel	OMNRF – Science and Research
Scott Reid	OMNRF – Science and Research
Mark Ridgway	OMNRF – Science and Research
Paul Gelok	MOECP – Ontario Parks
Jon Mee	Mount Royal University
Nick Mandrak	University of Toronto Scarborough
Brian Weidel	USGS

SOURCES OF INFORMATION

This Science Advisory Report is from the March 2–4, 2021 regional peer review on the Recovery Potential Assessment of Lake Whitefish (*Coregonus clupeaformis*), Lake Opeongo large-bodied Designatable Unit and Lake Opeongo small-bodied Designatable Unit. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Brooke, L.T. 1975. Effect of different constant incubation temperatures on egg survival and embryonic development in Lake Whitefish (*Coregonus clupeaformis*). Trans. Am. Fish. Soc. 104(3): 555–559.

Challice, A.R., Milne, S.W., and Ridgway, M.S. 2019. Does habitat occupancy by lake trout and lake whitefish in large lakes match published thermal habitat envelopes? Ecol. Freshw. Fish 28(4): 611–623.

Claramunt, R.M., Muir, A.M., Johnson, J., and Sutton, T.M. 2010. Spatio-temporal trends in the food habits of age-0 lake whitefish. J. Great Lakes Res. 36(Suppl. 1): 66–72.

Coker, G. A., Ming, D.L., and Mandrak, N.E. 2010. Mitigation guide for the protection of fishes and fish habitat to accompany the species at risk recovery potential assessments conducted by Fisheries and Oceans Canada (DFO) in Central and Arctic Region. Version 1.0. Can. Manuscr. Rep. Fish. Aquat. Sci. 2904: vi + 40 p.

Colm, J.E., and Drake, D.A.R. 2022. Information in support of a Recovery Potential Assessment of Lake Whitefish (Coregonus clupeaformis), Lake Opeongo large-bodied and small-bodied Designatable Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/044. iv + 40 p.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2018. COSEWIC assessment and status report on the Whitefish *Coregonus* spp., European Whitefish - Squanga Lake small-bodied population (*Coregonus lavaretus*), Lake Whitefish - Squanga Lake large-bodied population (*Coregonus clupeaformis*), European Whitefish - Little Teslin Lake small-bodied population (Coregonus *lavaretus*), Lake Whitefish - Little Teslin Lake large-bodied population (*Coregonus clupeaformis*), European Whitefish - Dezadeash Lake small-bodied population (*Coregonus lavaretus*), European Whitefish - Dezadeash Lake large-bodied population (*Coregonus lavaretus*), Lake Whitefish - Lake Opeongo small-bodied population (*Coregonus clupeaformis*), Lake Whitefish - Lake Opeongo large-bodied population (*Coregonus clupeaformis*), Lake Whitefish - Como Lake small-bodied population (*Coregonus clupeaformis*) and the Lake Whitefish - Como Lake large-bodied population (*Coregonus clupeaformis*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. xxxix + 42 p.

Cucin, D. and Faber, D.J. 1985. Early life studies of Lake Whitefish (*Coregonus clupeaformis*), Cisco (*Coregonus artedii*) and Yellow Perch (*Perca flavescens*) in Lake Opeongo, Ontario. Ontario Fish. Tech. Rep. Ser. 16: 27 p.

DFO. 2007. Revised protocol for conducting recovery potential assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/039.

DFO. 2014. Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (*Erratum*: June 2016)

DFO. 2017. National Code on Introductions and Transfers of Aquatic Organisms. Fisheries and Oceans Canada, Ottawa, ON. ii + 41 p.

Edsall, T.A. 1999a. The growth-temperature relation of juvenile Lake Whitefish. Trans. Am. Fish. Soc. 128(5): 962–964.

Edsall, T.A. 1999b. Preferred temperatures of juvenile Lake Whitefish. J. Great Lakes Res. 25(3): 583–588.

Evans, D.O., and Waring, P. 1987. Changes in the multispecies, winter angling fishery of Lake Simcoe, Ontario, 1961-83: invasion by Rainbow Smelt, *Osmerus mordax*, and the roles of intra- and interspecific interactions. Can. J. Fish. Aquat. Sci. 44: 182–197.

Fishbase 2020. Length–Length parameters for *Coregonus clupeaformis*. List Length-Length Relationship - Species (fishbase.se) [accessed February 20, 2021]

Freeberg, M.H., Taylor, W.W., and Brown, R.W. 1990. Effect of egg and larval survival on year-class strength of Lake Whitefish in Grand Traverse Bay, Lake Michigan. Trans. Am. Fish. Soc. 199(1): 92–100.

Fudge, R.J.P., and Bodaly, R.A. 1984. Postimpoundment winter sedimentation and survival of lake whitefish (*Coregonus clupeaformis*) eggs in Southern Indian Lake, Manitoba. Can. J. Fish. Aquat. Sci. 41: 701–705.

Fung, S.R., van der Lee, A.S., and Koops, M.A. 2022. Recovery Potential Modelling of Lake Whitefish (*Coregonus clupeaformis*) in Lake Opeongo, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/043. iv + 28 p.

Gorsky, D., Zydlewski, J., and Basleu, D. 2012. Characterizing seasonal habitat use and diel vertical activity of Lake Whitefish in Clear Lake, Maine, as determined with acoustic telemetry. Trans. Am. Fish. Soc. 143(3): 761–771.

Gorsky, D., and Zydlewski, J. 2013. Experimental evaluation of size-dependent predation by adult post-spawned Rainbow Smelt on larval Lake Whitefish. N. Am. J. Fish. Manage. 33(1): 163–169.

Guzzo, M.M., and Blanchfield, P.J. 2017. Climate change alters the quantity and phenology of habitat for lake trout (*Salvelinus namaycush*) in small Boreal Shield lakes. Can. J. Fish. Aquat. Sci. 74: 871–884.

Hart, J.L. 1930. The spawning and early life history of the whitefish *Coregonus clupeaformis* (Mitchill), in the Bay of Quinte, Ontairo. Contrib. Can. Fish. Biol. 7: 165–214.

Herbst, S.J., Marsden, J.E., and Smith, S.J. 2011. Lake Whitefish in Lake Champlain after commercial fishery closure and ecosystem changes. N. Am. J. Fish. Manage. 31: 1106–1115.

Ihssen, P.E., Evans, D.O., Christie, W.J., Reckhan, J.A., and DesJardine, R.L. 1981. Life history, morphology, and electrophoretic characteristics of five allopatric stocks of Lake Whitefish (*Coregonus clupeaformis*) in the Great Lakes Region. Can. J. Fish. Aquat. Sci. 38: 1790–1807.

Jude, D.J., Tesar, F.J., and Tin, H.T. 1998. Spring distribution and abundance of larval fishes in the St. Mary's River, with a note on potential effects of freighter traffic on survival of eggs and larvae. J. Great Lakes Res. 24(3): 569–581.

Kennedy, W.A. 1943. The Whitefish, *Coregonus clupeaformis* (Mitchill), of Lake Opeongo, Algonquin Park, Ontario. On. Fish. Res. Lab. No. 62: 25 p.

Locke, A., Mandrak, N.E., and Therriault, T.W. 2010. A Canadian Rapid Response Framework for Aquatic Invasive Species. Can. Sci. Advis. Sec. Res. Doc. 2010/114 iv + 30 p.

Loftus, D.H., and Hulsman, P.F. 1986. Predation on larval Lake Whitefish (*Coregonus clupeaformis*) and Lake Herring (*C. artedii*) by adult Rainbow Smelt (*Osmerus mordax*). Can. J. Fish. Aquat. Sci. 43: 812–818.

McKenna, J.E., and Johnson, J.H. 2009. Spatial and temporal variation in distribution of larval lake whitefish in eastern Lake Ontario: signs of recovery? J. Great Lakes Res. 35(1): 94–100.

Mee, J.A., Bernatchez, L., Reist, J.D., Rogers, S.M., and Taylor, E.B. 2015. Identifying designatable units for intraspecific conservation prioritization: a hierarchical approach applied to the lake whitefish species complex (*Coregonus* spp.). Evol. App. 8(5): 423–441.

Pigeon, D., Chouinard, A., and Bernatchez, L. 1997. Multiple modes of speciation involved in the parallel evolution of sympatric morphotypes of Lake Whitefish (*Coregonus clupeaformis*, Salmonidae). Evol. 51(1): 196–205.

Pothoven, S.A., Hook, T.O., and Roswell, C.R. 2014. Feeding ecology of age-0 lake whitefish in Saginaw Bay, Lake Huron. J. Great Lakes Res. 40(Suppl.1): 148–155.

Pothoven, S.A. 2020. The influence of ontogeny and prey abundance on feeding ecology of age-0 Lake Whitefish (*Coregonus clupeaformis*) in southeastern Lake Michigan. Ecol. Freshw. Fish 29(1): 103–111.

Price, J.W. 1940. Time-temperature relations in the incubation of the whitefish, *Coregonus clupeaformis* (Mitchill). J. Gen. Phys. 449–468.

Reckahn, J.A. 1970. Ecology of young lake whitefish (*Coregonus clupeaformis*) in South Bay, Manitoulin Island, Lake Huron. *In* Biology of coregonid fishes. Edited by C.C. Lindsey and C.S. Woods. University of Manitoba Press, Winnipeg, MB. pp. 437–460.

Reid, S.M., Parna, M., and Reist, J.D. 2017. Collapse of Lake Whitefish *Coregonus clupeaformis* (Mitchill, 1818) species pair in Como Lake, Ontario. J. Appl. Ichthyol. 33(5): 933–939.

Ridgway, M., and Middel, T. 2020. From aquatic connectivity to aquatic conservation in Algonquin Provincial Park. Ontario Ministry of Natural Resources and Forestry, Science and Research Branch, Peterborough, ON. Science and Research Information Report IR-20: 41 p.

Rogers, S.M. 2009. Designatable units at an appropriate scale for the Lake Whitefish (*Coregonus clupeaformis*). Special Report prepared for the Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. iii + 67 p.

Sandercock, F.K. 1964. A contribution to the ecology of the whitefishes *Prosopium cylindraceum* and *Coregonus clupeaformis* of Algonquin Park, Ontario. M.Sc. thesis, Department of Zoology, The University of British Columbia, Vancouver B.C. 63 p.

Scott, W.B., and Crossman, E.J. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. No. 184. 1998 Reprint. 996 p.

Trudel, M., Tremblay, A., Schetagne, R., and Rasmussen, J.B. 2001. Why are dwarf fish so small? An energetic analysis of polymorphism in lake whitefish (*Coregonus clupeaformis*). Can. J. Fish. Aquat. Sci. 58: 394–405.

Wood, J. 2016. Current status of Lake Whitefish in Maine; an update to MDIFW's 2001 whitefish assessment. Maine Department of Inland Fisheries and Wildlife, Fisheries and Hatcheries Division, Fishery Final Report Series No. 14-01: ii + 60 p.

THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Ontario and Prairie Region
Fisheries and Oceans Canada
Complete mailing address of CSA Office

E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-43833-7 N° cat. Fs70-6/2022-019E-PDF

Correct Citation for this Publication:

DFO. 2022. Recovery Potential Assessment of Lake Whitefish (*Coregonus clupeaformis*), Lake Opeongo Large-bodied Designatable Unit and Lake Opeongo Small-bodied Designatable Unit. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/019

Aussi disponible en français :

*MPO. 2022. Évaluation du potentiel de rétablissement du grand corégone (*Coregonus clupeaformis*) pour les unités désignables d’individus de grande taille et d’individus de petite taille du lac Opeongo. Secr. can. des avis sci. du MPO. Avis sci. 2022/019.*